Estimating Convective Entrainment Rates Associated with Deep Convection Using Aura CO, CALIPSO/CloudSat, and AIRS Observations and Comparison with GEOS-5 Simulations

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Motivation: ACMAP Project

- As convection usually occurs at horizontal scales smaller than the grid sizes of general circulation models (GCMs), the effects of convection are represented statistically through the use of parameterizations as functions of resolved atmosphere state variables.

- The most common way to parameterize convective transport is through mass flux schemes.

- A key process that modifies the mass flux is the mixing between convective plumes and their environment by entrainment and detrainment processes that describe, respectively, the inflow of environmental air into the convection and the outflow from the convective column into the environment.

Motivation: ACMAP Project

- A number of studies have documented the strong sensitivity of model performances in precipitation, cloud, and trace gases to entrainment rate (ER) parameterizations.

  (Wang et al. 2007; Del Genio et al. 2012; Kim et al. 2012; Yao and Cheng 2012; Oueslati and Bellon 2013 Field et al. 2014, 2015;)

Goal of this Study

- Goal: Improve the simulation of convection and its impacts through observational constraints on one of the most uncertain and important model physical parameters, the entrainment rate.

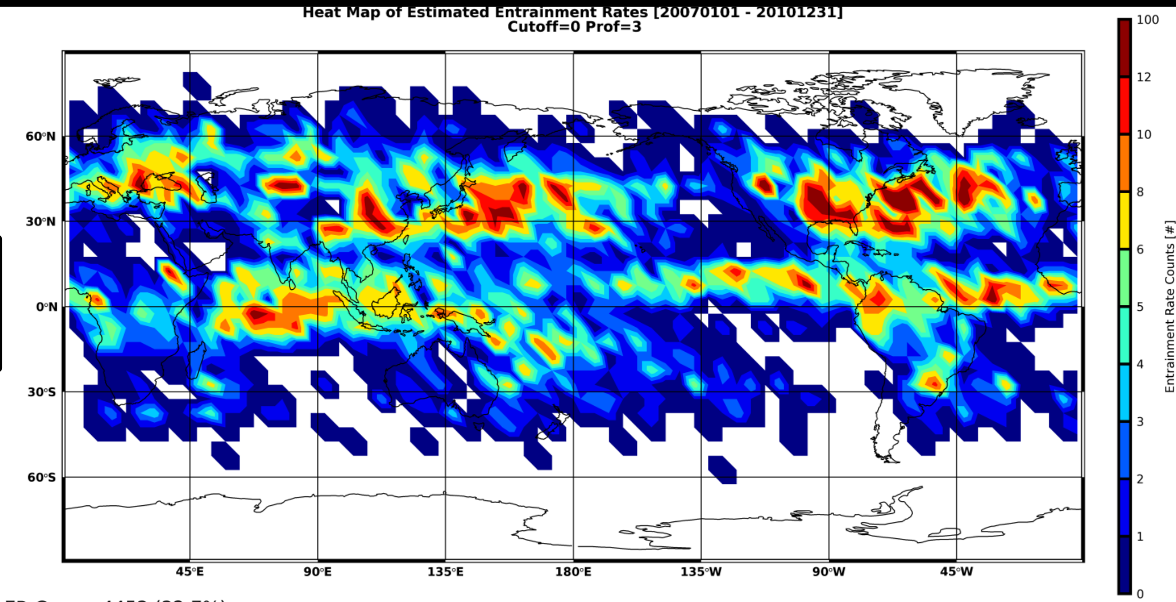
Perks of this Study

- Previous studies estimated entrainment rate using in-situ measurements of limited cases.

- This study uses satellite measurements to estimate entrainment rate for convection over the globe.

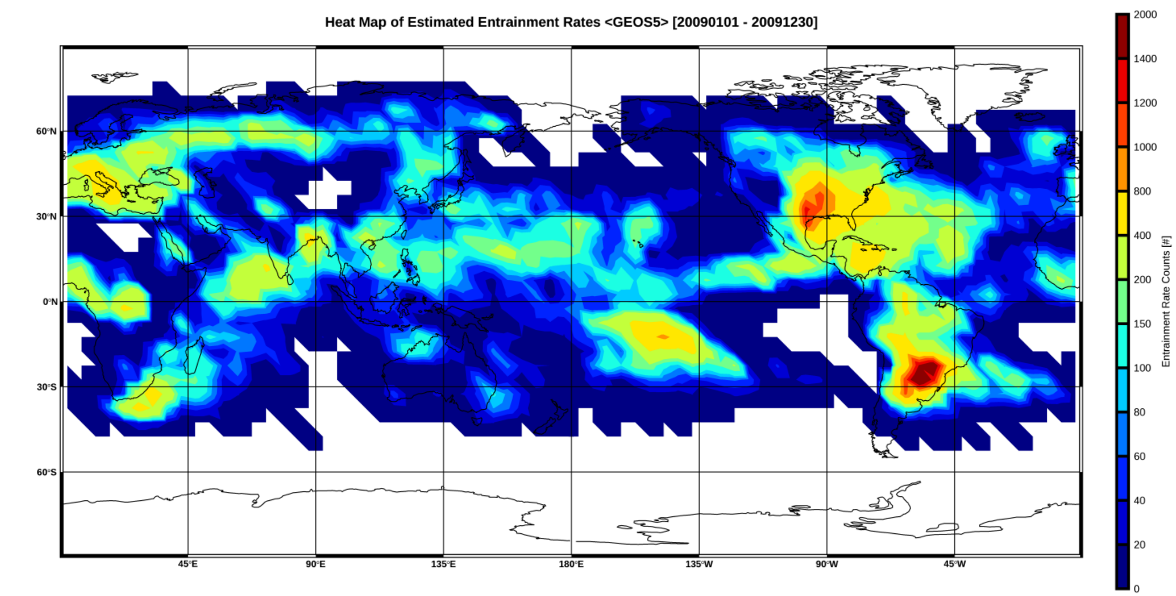
Distribution of Valid ER Retrievals

OBS



ER Cases: 4453 (32.7%)

GEOS-5



ER Cases: 139475.

Grid: 5.0° (lon) X 5.0° (lat)

Data Used

[Observations] Level 2, daily swath data

- **TES-MLS:** combined CO profile data (CO volume mixing ratio, pressure, altitude)

- **CloudSat/CALIPSO:** 2B-CLDCLASS-LIDAR data; combines CloudSat CPR and CALIPSO lidar (cloud type, cloud base, cloud top)

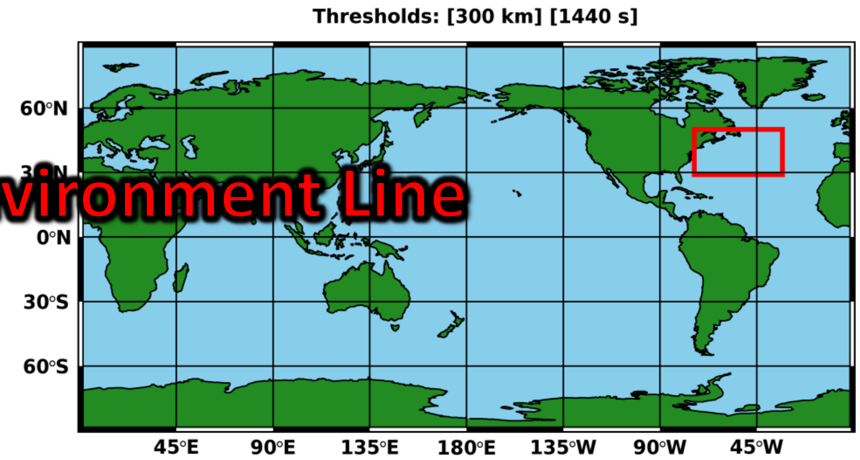
- **AIRS:** AIRX2RET data (relative humidity, CAPE)

[Model] 6-hourly gridded model output

- **GEOS-5:** model data

[Time Periods]

- Observational : 01 / 2007 – 12 / 2010
- GEOS-5 Model : 01 / 2009 – 12 / 2009



CO Environment Line

Colo-C/CS (line)

e of Colocation

Mass Flux:

$$\frac{\partial \eta(z)}{\partial z} = \sigma$$

where,

$\eta(z)$ is the normalized mass flux at height (z) relative to cloud base

σ is the entrainment ratio ($^{\%}/_{km}$)

$$CO_{parcel}(z + \Delta z) = \left[\frac{CO_{parcel}(z) + \sigma \Delta z\, CO_{environment}(z)}{(1+\sigma\Delta z)}\right],$$

where,

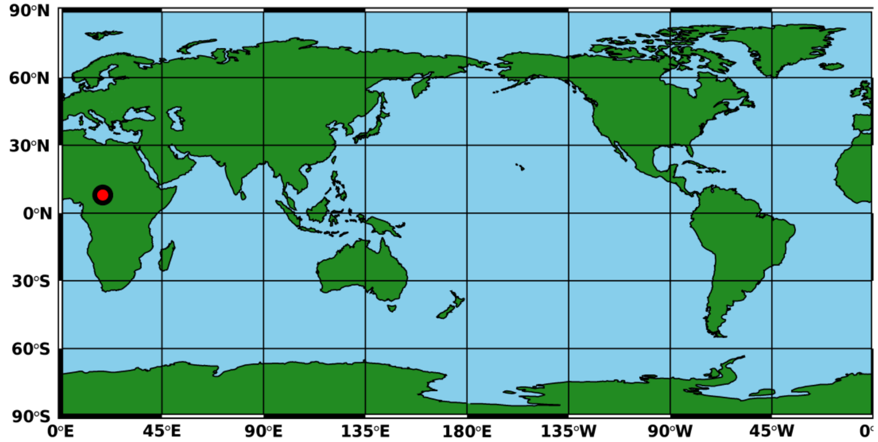
σ is the entrainment ratio ($^{\%}/_{km}$)

Δz is the height change between different pressure levels

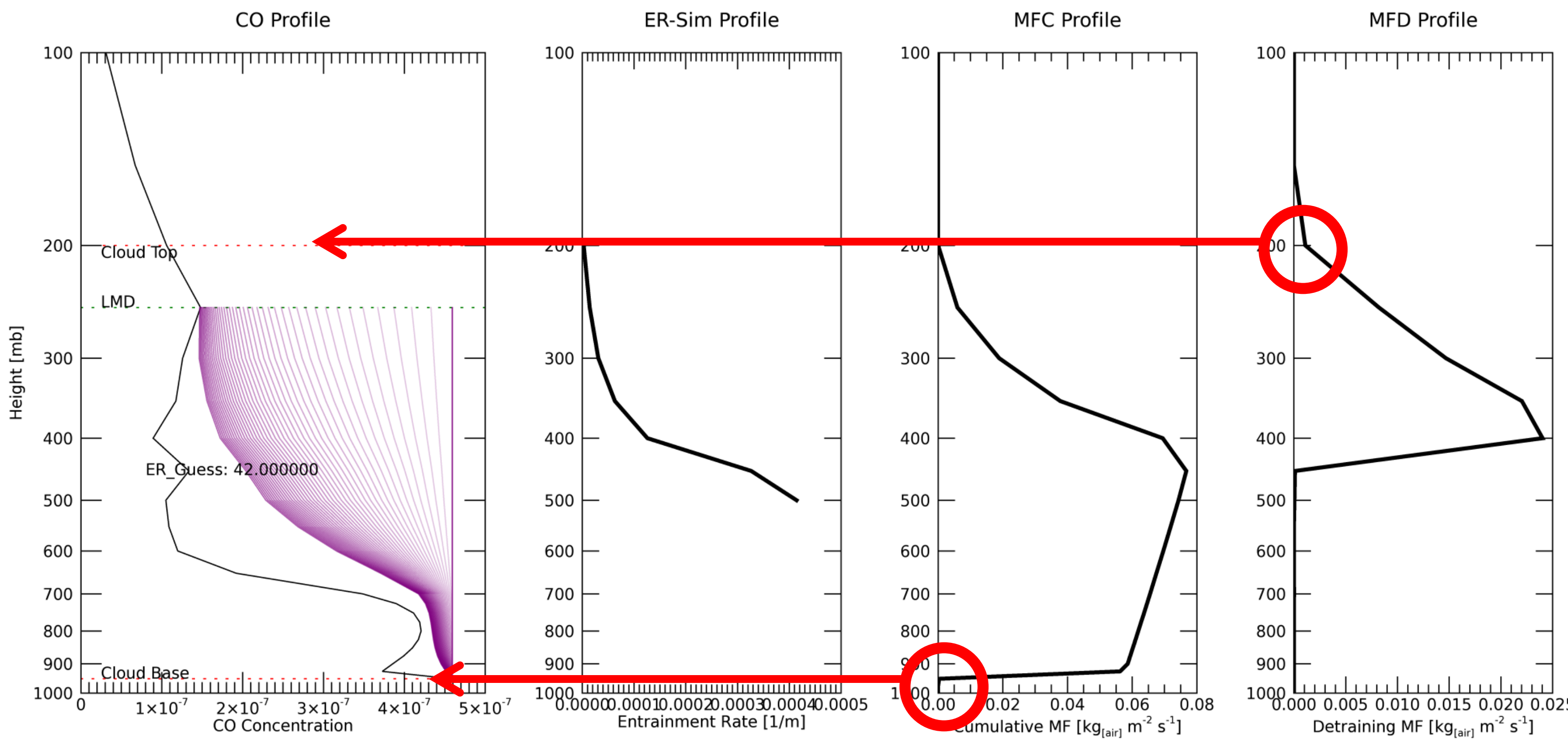
GEOS - 5

Date: 2009/01/01
[Case = 5684]
[Count = 93]

LAT: 8.0000000
LON: 18.750000



Height [mb]



CO Concentration

ER

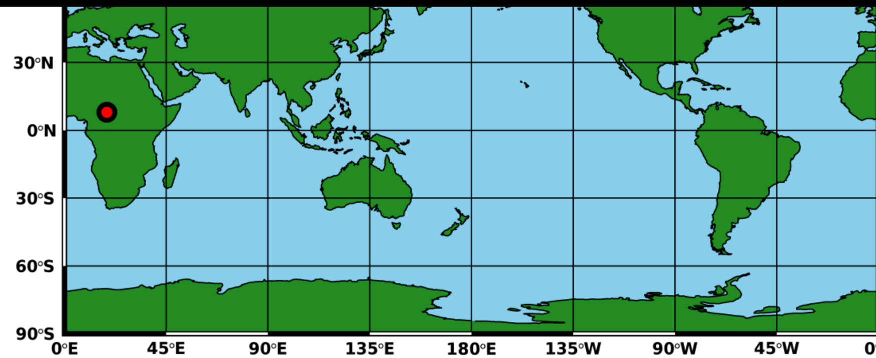
Cumulative MF

Detraining MF

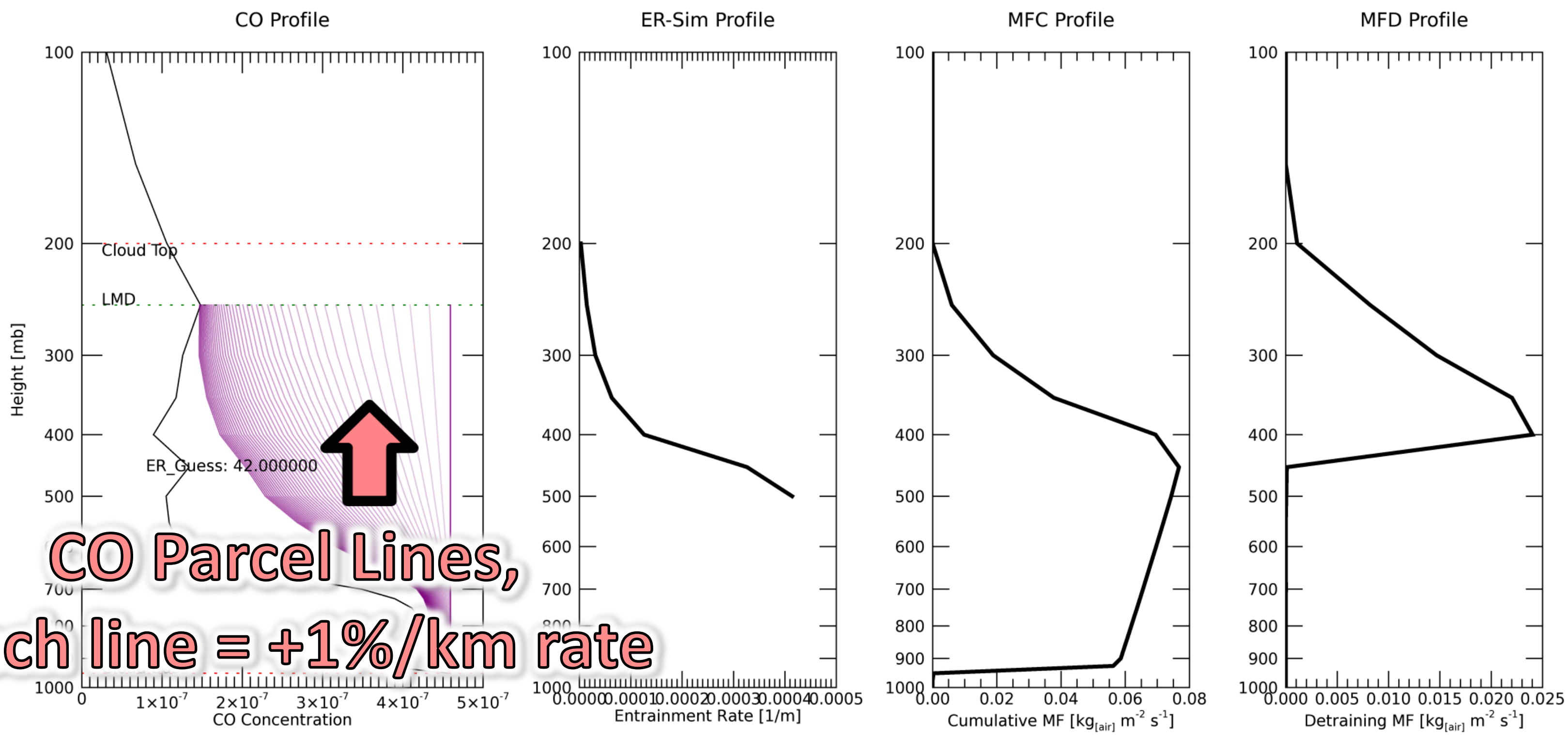
Method 1 – Plume Model

Date: 2009/01/01
[Case = 5684]
[Count = 93]

LAT: 8.0000000
LON: 18.750000



Height [mb]



CO Concentration

ER

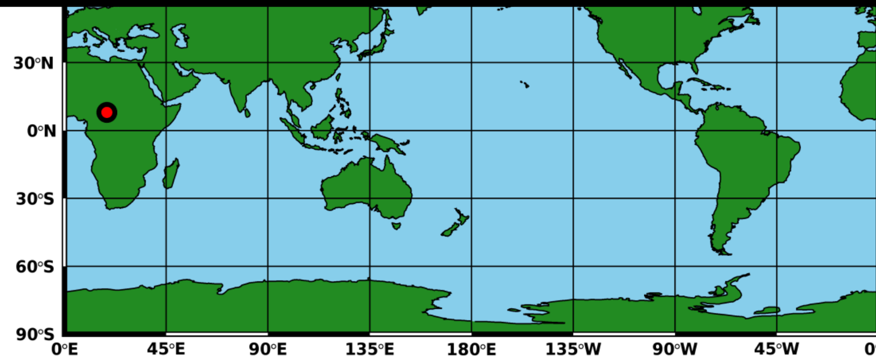
Cumulative MF

Detraining MF

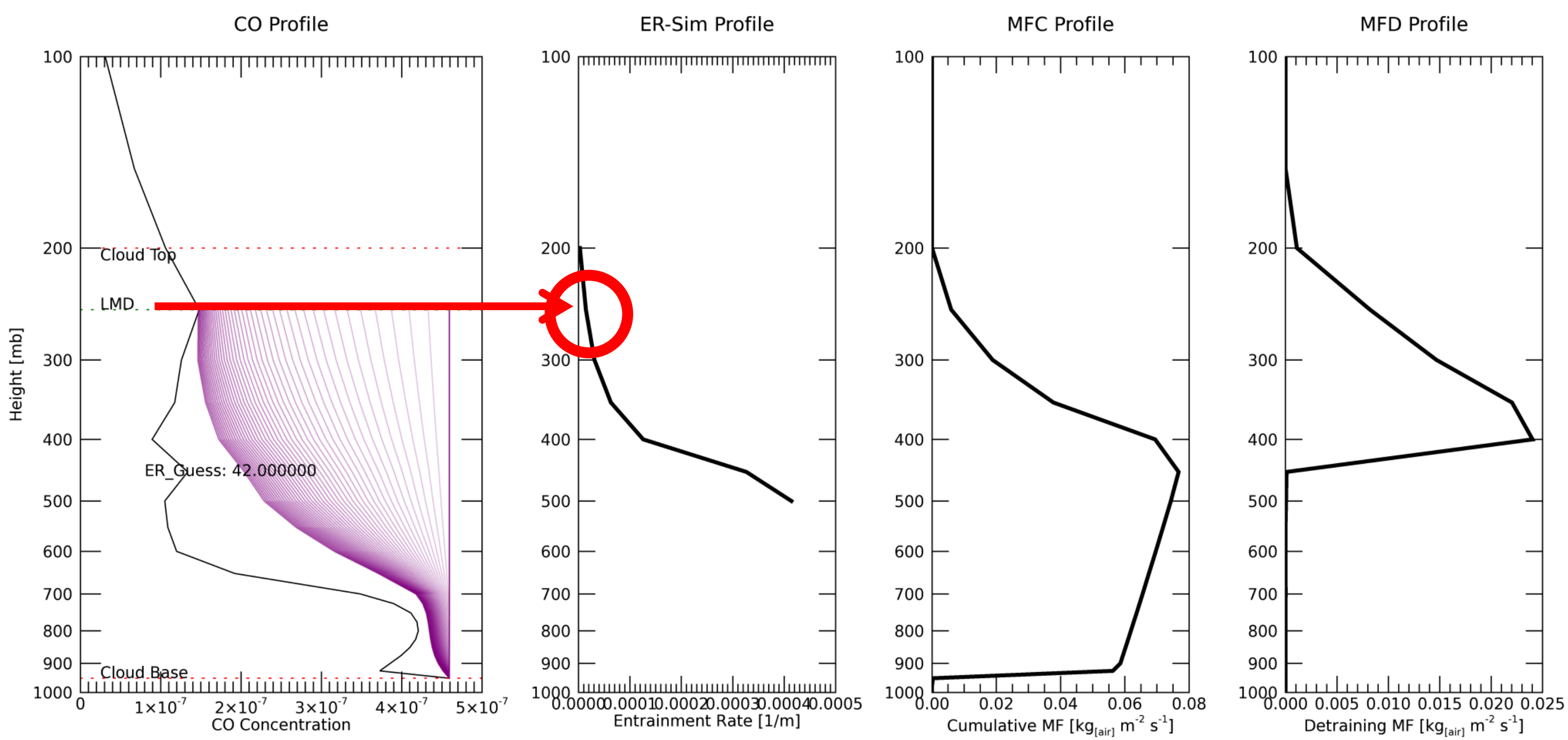
Method 2 – Model Given

Date: 2009/01/01
[Case = 5684]
[Count = 93]

LAT: 8.0000000
LON: 18.750000

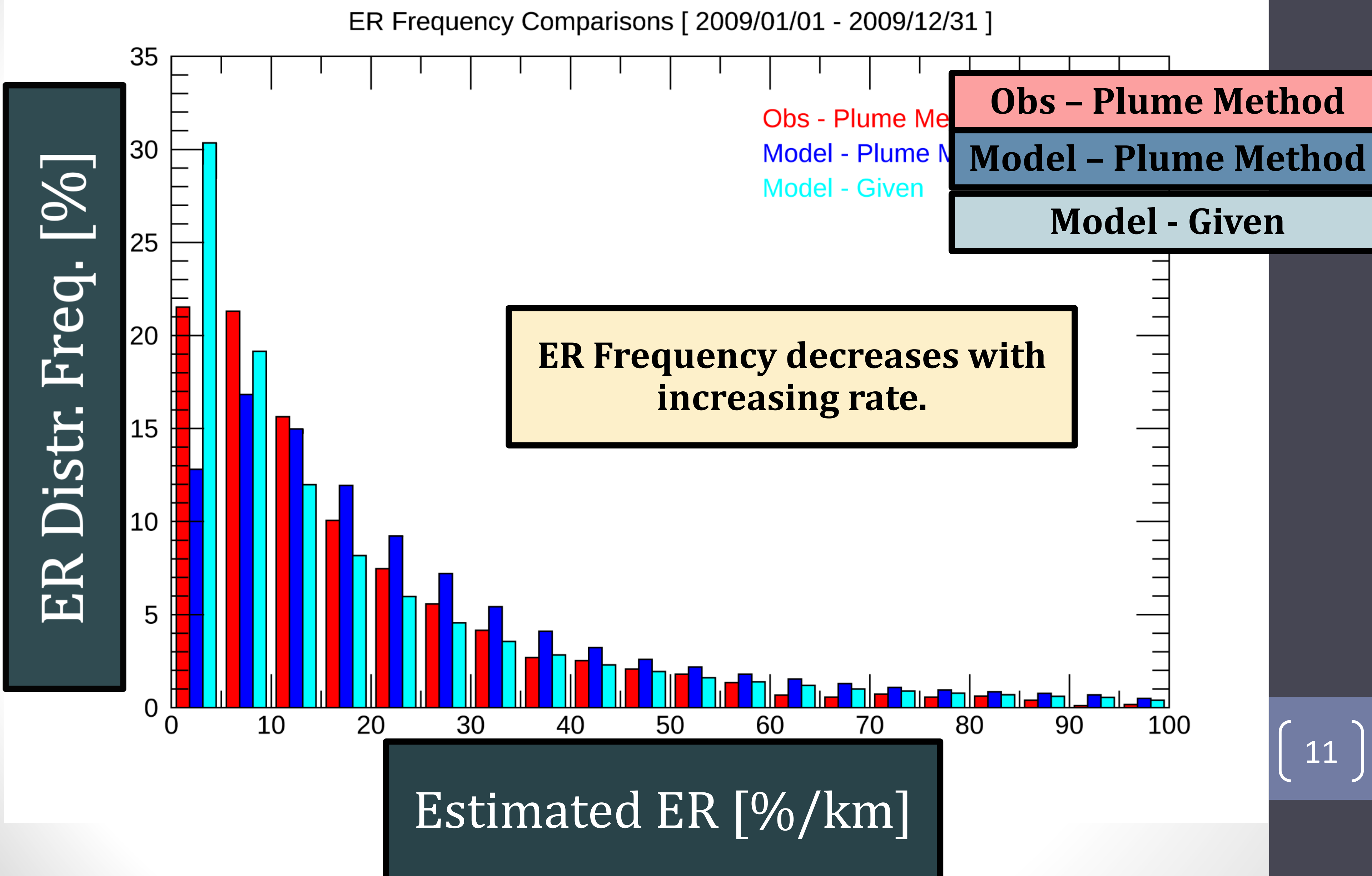


Height [mb]

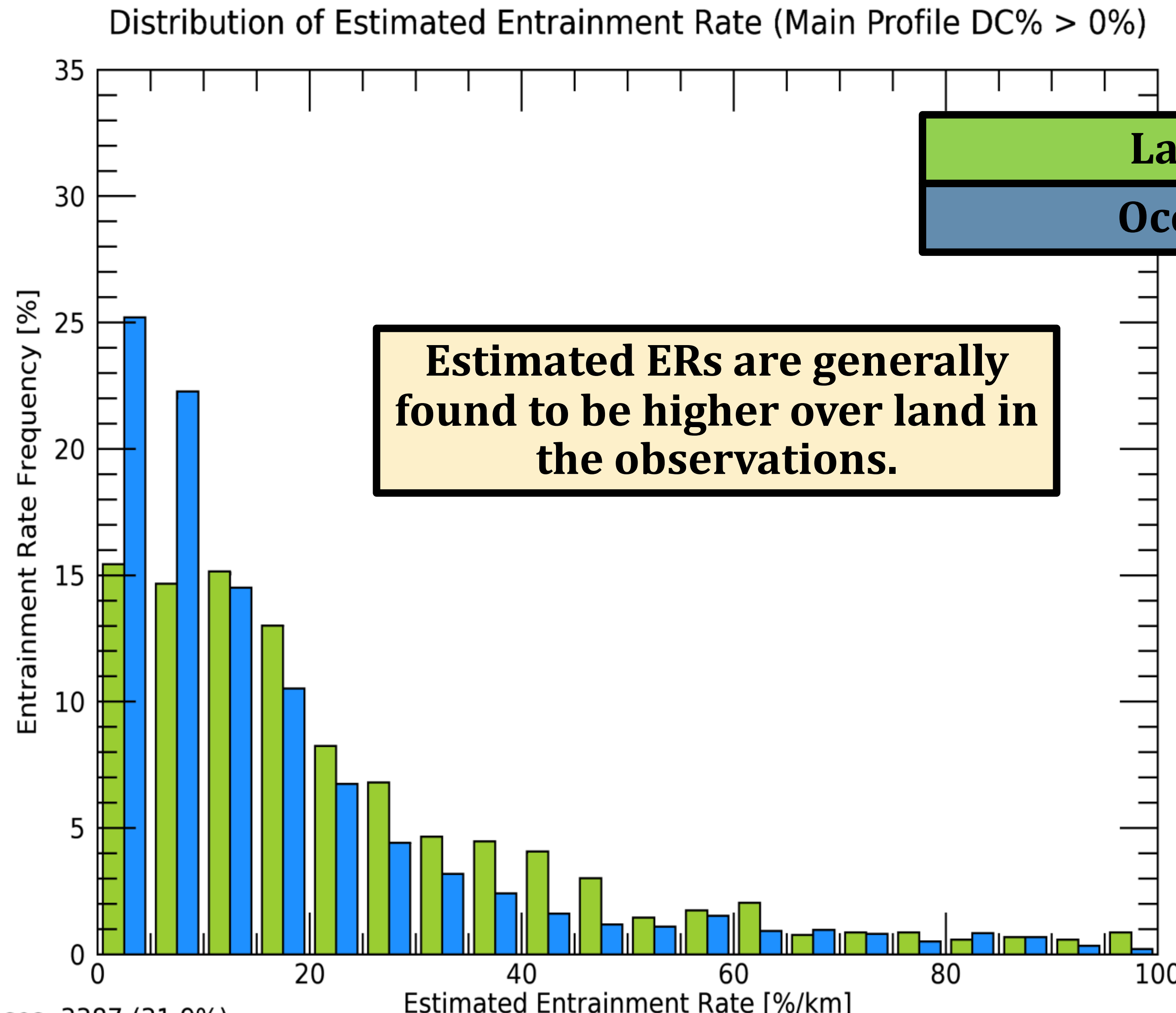


CO Concentration | ER | Cumulative MF | Detraining MF

ER Distribution by Method/Source



ER Distribution – Split by Land and Ocean Surface



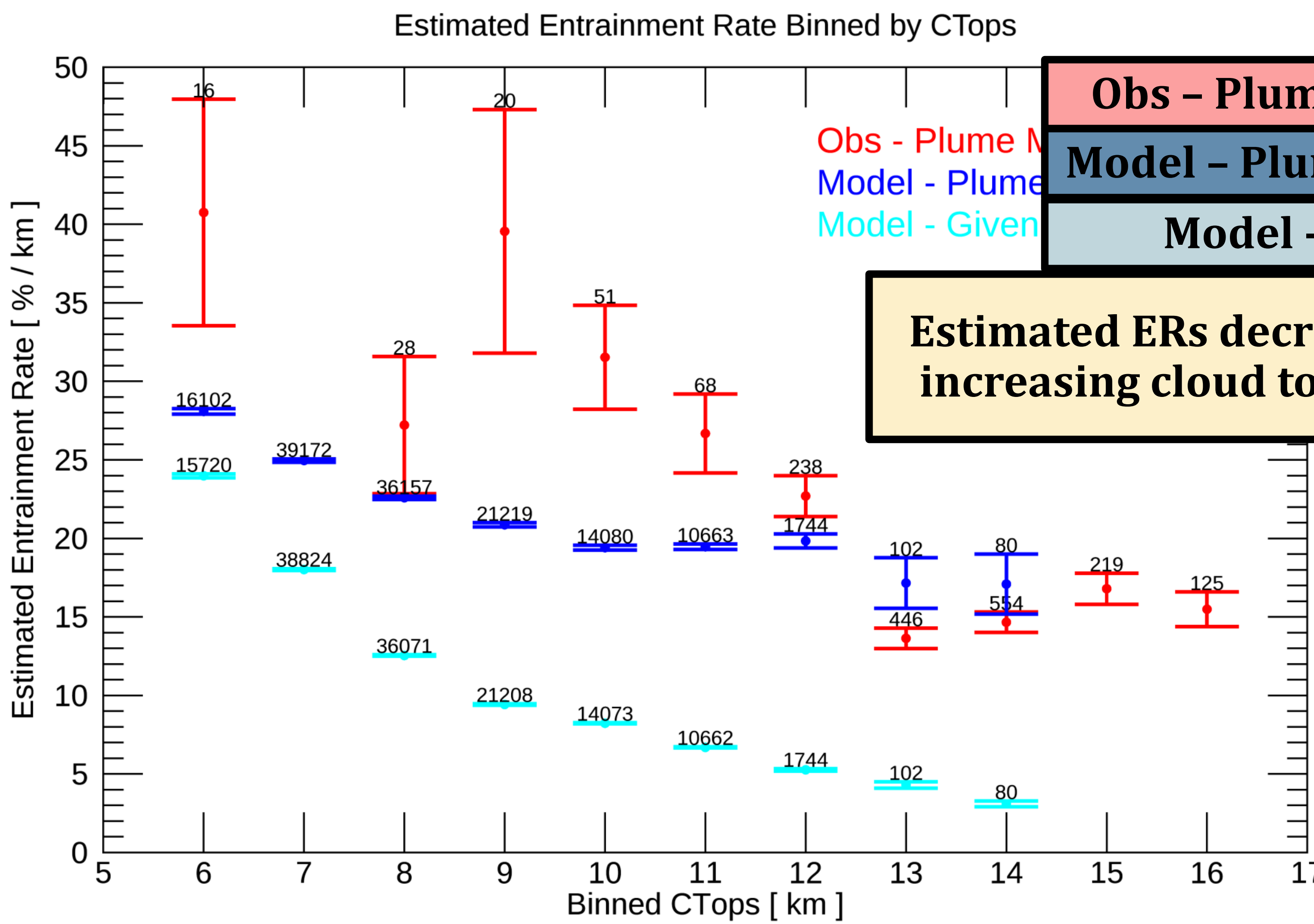
Land

Ocean

Estimated ERs are generally found to be higher over land in the observations.

ER Cases: 3387 (31.9%)
Land Cases: 1030 (2552)
Ocean Cases: 2357 (8050)

ER Distribution – Binned by Cloud Top Height



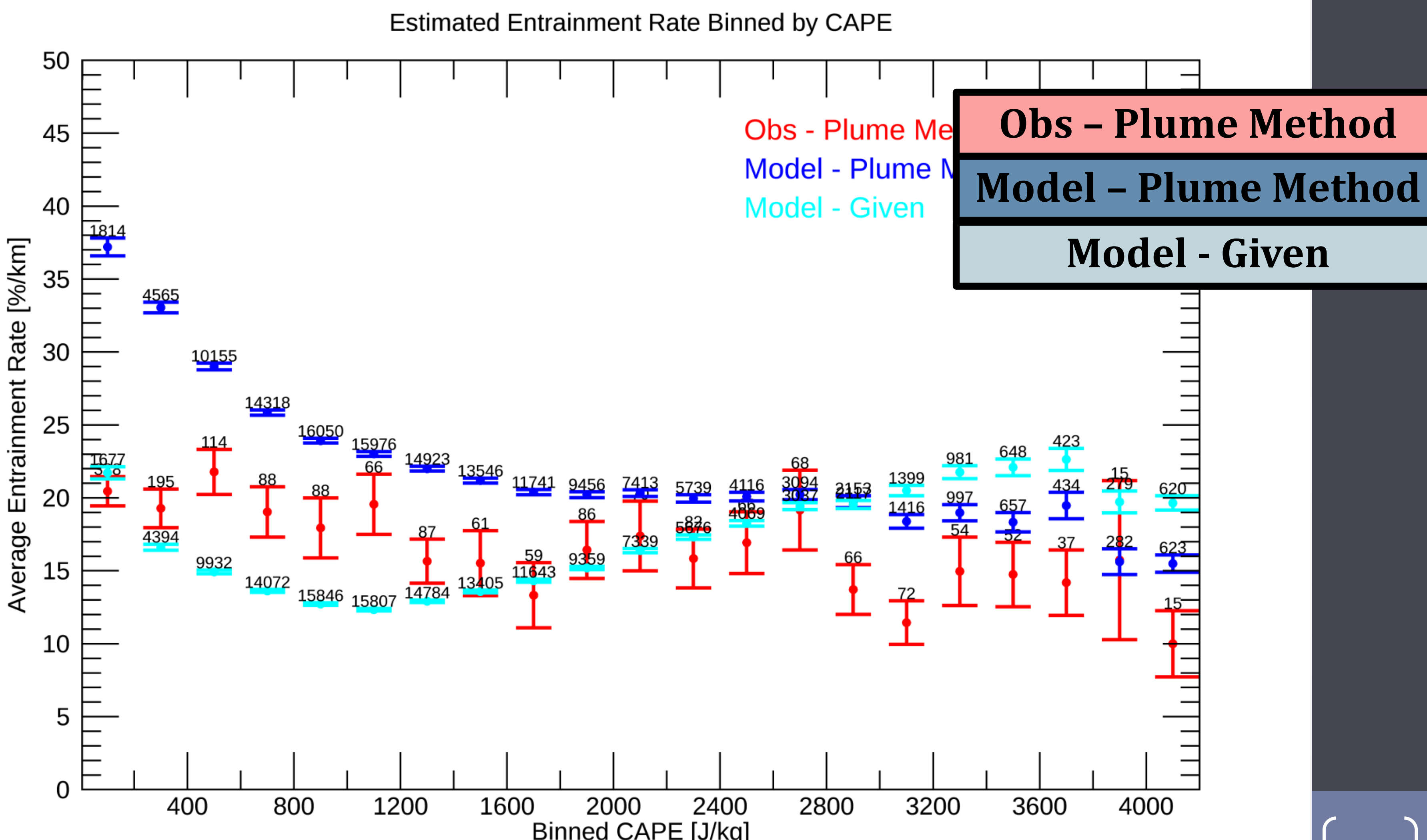
Obs – Plume Method

Model – Plume Method

Model - Given

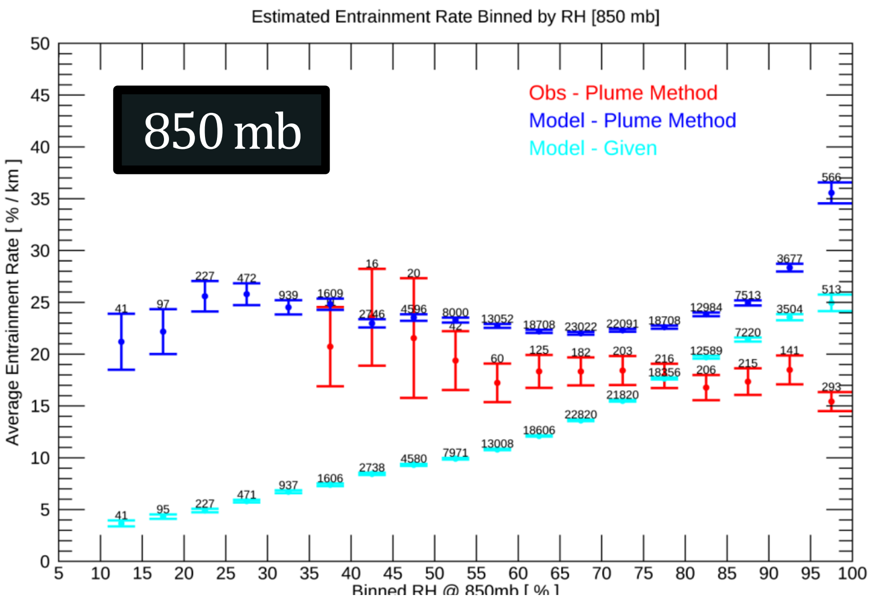
Estimated ERs decrease with increasing cloud top height.

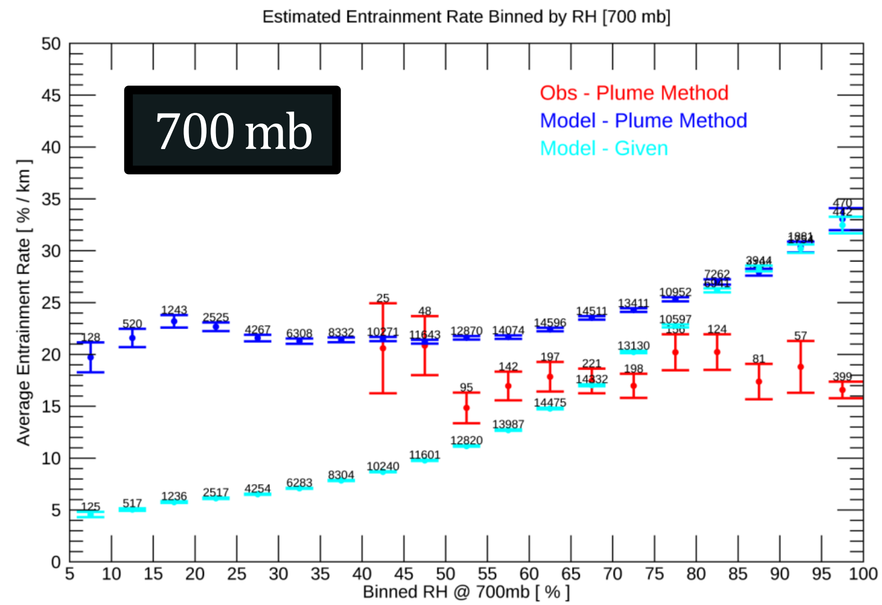
ER Distribution – Binned by CAPE

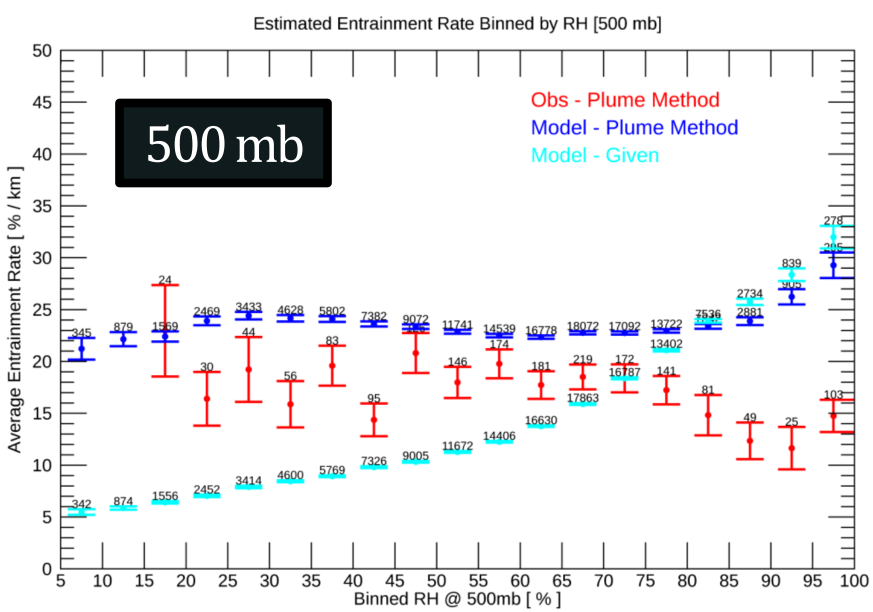


Estimated ERs decrease with increasing CAPE using both plume methods, however, ERs used directly in the GEOS-5 model show strong decrease followed by an increase in ER with CAPE.

ER Distribution – Binned by Relative Humidity







Model plume estimated ERs and given ERs increase with increasing RH, while the observation-based ER does not vary much with RH.

Obs – Plume Method

Model – Plume Method

Model – Given

Summary

- A decrease in frequency of estimated/given ER with increasing ER, meaning estimated and given ERs were found to be predominately below 20 %/km.
- Comparing land/ocean cases using TES/MLS CO profiles found higher estimated ERs over land compared to over ocean.
- A decrease in estimated ER is found with increasing cloud top height. GEOS-5 simulated ERS are found to be much lower especially at higher clout top heights.
- Estimated ERs decrease with increasing CAPE using both plume methods, however, ERs used directly in the GEOS-5 model shows a strong decrease followed by an increase in ER with CAPE.
- Model plume estimated ERs and given ERs increase with increasing RH, while the observation-based ER does not vary much with RH.